Evaluation of aerosol properties over ocean from Moderate Resolution Imaging Spectroradiometer (MODIS) during ACE-Asia

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[1] The Aerosol Characterization Experiment-Asia (ACE-Asia) was conducted in March–May 2001 in the western North Pacific in order to characterize the complex mix of dust, smoke, urban/industrial pollution, and background marine aerosol that is observed in that region in springtime. The Moderate Resolution Imaging Spectroradiometer (MODIS) provides a large-scale regional view of the aerosol during the ACE-Asia time period. Focusing only on aerosol retrievals over ocean, MODIS data show latitudinal and longitudinal variation in the aerosol characteristics. Typically, aerosol optical depth (τ_a) values at 0.55 μm are highest in the 30°–50° latitude band associated with dust outbreaks. Monthly mean τ_a in this band ranges ~0.40–70, although large differences between monthly mean and median values indicate the periodic nature of these dust outbreaks. The size parameters, fine mode fraction (η), and effective radius (r_{eff}) vary between monthly mean values of η = 0.47 and r_{eff} = 0.75 μm in the cleanest regions far offshore to approximately η = 0.85 and r_{eff} = 0.30 μm in near-shore regions dominated by biomass burning smoke. The collocated MODIS retrievals with airborne, ship-based, and ground-based radiometers measurements suggest that MODIS retrievals of spectral optical depth fall well within expected error ($\Delta\tau_a = \pm 0.03 \pm 0.05\tau_a$) except in situations dominated by dust, in which cases MODIS overestimate both the aerosol loading and the aerosol spectral dependence. Such behavior is consistent with issues related to particle nonsphericity. Comparisons of MODIS-derived r_{eff} with AERONET retrievals at the few occurrences of collocations show MODIS systematically underestimates particle size by 0.2 μm. Multiple-year analysis of MODIS aerosol size parameters suggests systematic differences between the year 2001 and the years 2000 and 2002, which are traced to instrumental electronic cross talk. Sensitivity studies show that such calibration errors are negligible in τ_a retrievals but are more pronounced in size parameter retrievals, especially for dust and sea salt.

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1. Introduction

[2] For over two decades much research has been devoted to studies of the effects of Saharan dust on the Earth's radiative balance [*Carlson and Benjamin*, 1980; *Tegen and Fung*, 1994, 1995; *Tegen et al.*, 1996; *Li et al.*, 1996; *Andreae*, 1996; *Hsu et al.*, 2000; *Haywood et al.*, 2003], atmospheric chemistry [*Dentener et al.*, 1996], and biogeochemical cycle [*Swap et al.*, 1992]. In contrast, Asian dust has received much less scrutiny by the global community. In Asia, although dust storms occur year-round in the source region, dust outbreaks appear to be the strongest in springtime based upon 40 years ground observations [*Sun et al.*, 2001]. However, it has been a difficult task to characterize composition of the Asian dust outbreaks because the air mass includes not only dust particles but the growing and variable sources of the precursors of water soluble aerosols, such as NO_x and SO_2 gases [*Elliot et al.*, 1997; *VanArdeen*

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et al., 1999]. A multinational, multiplatform field campaign, so-called the Aerosol Characterization Experiment, Asia (ACE-Asia), was therefore planned and executed in March–May 2001 to study aerosol physical, chemical, and radiative properties in east Asia and the western Pacific Ocean [*Huebert et al.*, 2003].

[3] Asian dust storms rising from the Taklimakan and Gobi deserts (as well as neighboring areas), sweeping through east Asia are closely associated with frontal development and Mongolian cyclonic depressions. The dust-laden air mass can travel long distance reaching as far as the United States and beyond. Drought in northern and northwestern China is believed to play a critical role in the increasing frequency, intensity, duration, and area of occurrence of dust outbreaks in the past few years. In addition, the loss of vegetation due to agricultural and livestock breeding activities (e.g., at a rate of 400 million km^2 per year) in northwestern China has also contributed significantly to the total dust emission of 800 million tons annually. In spring 2001, 3 strong, 10 moderate, and 5 weak outbreaks occurred in northern China with 41 dusty days recorded in the region. Unlike Saharan dust storms dominated by dust particles, Asian dust clouds are often mixed with urban/industrial pollutants. By serving as the reactive surface, dust particles can modify chemical processes of the formation of acid gases (e.g., H_2SO_4 and HNO_3) [*Tabazadeh et al.*, 1998; *Goodman et al.*, 2000; *Phadnis and Carmichael*, 2000; *Terada et al.*, 2002]. Biomass burning from Southeast Asia, as a result of agricultural cleaning, is responsible for emitting significant amounts of soot to the atmosphere. The smoke plumes carried by the southwesterlies can mix with pollution (and dust) over the western Pacific Ocean before reaching further downwind regions. It is evident that elevated CO ($\sim$10%), PM_{10} ($\sim$50%) and PAN (Peroxyacetylnitrate) ($\sim$100%) concentrations were observed in the free atmosphere in western US during springtime [*Jaffe et al.*, 1999].

[4] The purpose of this paper is to evaluate the accuracy of MODIS-derived aerosol properties (τ_a, η and r_{eff}) over the western Pacific Ocean in March–May 2001 during the ACE-Asia field campaign. As found, dust nonsphericity and MODIS sensor calibration issues in shortwave infrared (SWIR) further complicate the columnar aerosol retrieval with variable aerosol sources (dust, pollution, and smoke) and vertical distributions. Terra-MODIS sensor electronics was switched from side A to side B (for better ocean color retrieval from less noisy ocean bands) on 30 October 2000 and later switched back to side A on 2 July 2001 (after side B power supply failed in mid-June). Though similar optical calibrations were done prior to and post the switch, the level 1B (L1B) SWIR (i.e., 1.24, 1.64, and 2.1 μm) band radiances could be different due to the out-of-band thermal leak (3–5 μm) and electronic cross talk (residual electrons from imperfect detector reset of the 500 m resolution subframes) [*Xiong et al.*, 2003]. The differences may have caused the anomalies in the MODIS-derived size parameters since the weighting between the fine and coarse mode aerosols obtained in the retrieval is attributed to the spectral curvature of measurements from the visible (i.e., 0.55, 0.66, 0.87 μm without thermal leak and electronic cross talk) all the way through the SWIR bands. The details of the derivation of τ_a, η and r_{eff} using the visible-SWIR bands are documented in the work of *Remer et al.* [2005]. In section 2, we briefly describe MODIS aerosol retrieval algorithm over ocean and the expected accuracies of retrieved parameters. In section 3, we analyze the latitudinal and regional distribution and variation as a preview before validation.

9. Concluding Remarks

[34] Aerosol retrievals from MODIS provide a wide regional view of aerosol loading and particle size across the northwestern Pacific during the ACE-Asia field experiment in spring 2001. In general, there is a decrease in τ_a with the distance eastward from the Asian continent. The highest aerosol loading (monthly mean τ_a $\sim$0.40–0.70) occurs in the belts associated with periodic dust transport events (30°–50°N). The lowest aerosol loading (monthly mean τ_a $\sim$0.08–0.12) occurs in the southeastern edges of our domain (10°–20°N; 150°–160°E). The monthly mean η varies between approximately 0.5 in the cleanest regions to approximately 0.8 in near the coast of Southeast Asia dominated by biomass burning smoke. Conversely, the monthly mean r_{eff} ranges between approximately 0.8 and 0.3 μm.

[35] The validation of τ_a in ACE-Asia leads to similar conclusions as obtained from the globe and from different parts of the world ($\Delta\tau_a = \pm 0.03 \pm 0.05\tau_a$). The collection 4 MODIS-derived τ_a values in ACE-Asia are in good agreement (SRMSE $\leq$0.05) with spaceborne and shipborne Sun photometer/radiometers (AATS-14, AATS-6, Microtops, Simbad, SimbadA, and shadowband radiometer) in the absence of dust, and consistently larger errors across the spectrum (0.47–2.1 μm) are found during dust outbreaks (SRMSE $\sim$0.1–0.3). Aerosol loading is least affected by electronic cross talk as shown by the sensitivity study (within ±0.05). Dust nonsphericity is considered to be responsible for the overestimated aerosol loading.

[36] The MODIS-derived regional monthly η range (0.4–0.9) during ACE-Asia in 2001 is higher than the range found in the same region in 2000 (0.1–0.9) and in 2002 (0.2–0.9). Conversely, the MODIS-derived r_{eff} is lower in 2001 (0.2–0.8 μm) than in 2000 (0.2–1.3 μm) or in 2002 (0.2–1.2 μm). Sensitivity studies depict that the variation in the SWIR band radiances on the order of expected residual cross talk can change aerosol model selections in the retrieval, and introduce errors to aerosol size parameters. The effect of electronic cross talk is greater for low aerosol loading (e.g., remote pristine ocean) and also for dust- than pollution-dominated conditions. The missing coarse mode (>1 μm) of the monthly mean r_{eff} in remote pristine oceans (τ_a < 0.15) is evident for the anomalies of retrievals from side B as opposed to side A electronics. Collectively, about 80% of the points (regional monthly means from March to May) from side B (2001) retrievals fall within the range of r_{eff} between 0.3 and 0.5 μm in corresponding to τ_a $\sim$0.15–0.9; large values of r_{eff} $\sim$0.6–0.8 μm are only seen for $\tau_a \leq$ 0.1. It is an artifact most likely resulted from electronic cross talk in the SWIR bands rather than interannual variability since interannual variability should only change the intensity, not the range, of the parameters. The r_{eff} values derived in ACE-Asia can be estimated $\sim$100% smaller for $\tau_a \leq$ 0.10, 50–60% for τ_a $\sim$0.1–0.3, 20–30% for τ_a $\sim$0.3–0.5, and 10–15% for $\tau_a \geq$ 0.5.

[37] Owing to the nature of scene-dependent electronic cross talk, the correction set at one level may not be adequate for another. Unless MODIS electronic cross-talk effects can be completely removed or fully characterized, the evaluation of the uncertainties of MODIS-retrieved aerosol size parameters remains inconclusive in ACE-Asia, and may be largely the case for the entire period of side B electronics.